

ENVIRONMENTAL IMPACT OF HEAVY METALS CONTAINED IN FLY ASH EMITTED FROM THE THAI LIGNITE-FIRED POWER PLANT

Vladimir Kouprianov¹ and Vladimir Bashkin²

¹Department of Mechanical Engineering, Sirindhorn International Institute of Technology,
Thammasat University, Pathumthani 12121, Thailand.

²Joint Graduate School of Energy and Environment, King Mongkut's University of Technology
Thonburi, Bangkok 10140, Thailand.

ABSTRACT - In this work, the highly hazardous heavy metals (HM) are the focus of an assessment of the environmental impact of the Mae Moh Power Plant (Northern Thailand) fired with Thai lignites. The synergetic environmental impacts associated with the high sulfur content in the fuel (average value of 3.3% and maximum up to 7.0%) and the presence of a large number of heavy metals (As, Ba, Ce, Co, Cr, Cs, Ni, U, Rb, Sr, Th, etc) in the fly ash have been assumed in the model. Using data on the fly ash emission and HM content in the fly ash, the amount of heavy metals emitted from the lignite-fired boilers of the Mae Moh Power Plant was predicted. Calculation of the approximate rates of HM depositions was then conducted and the predicted values were compared with the corresponding element contents in regional soils. For various scenarios of power plant operation conditions and affected area, the environmental impact of heavy metals on that area was estimated. The results show the dangerous tendency of the HM accumulation in soil organic matter under certain conditions.

KEYWORDS: Environmental impact, heavy metals, Thai lignite-fired boilers.

INTRODUCTION

The power production sector of the Thai economy is the strongest emitter of suspended particulate matter (SPM) into environment. Annually, more than 1 Mton, or 80 % of the total SPM emission (referred to as fly ash), is discharged into the atmosphere from solid fuel-fired units, whereas the share of the SO_x emission from power generation accounts for 60 - 65 %. The contribution share of other pollutants (NO_x, CO₂, CO) formed in utility and industrial boilers is much lower (Chungpaibulpatana et al., 1997).

At present, Thai lignite is the major solid fuel used for power generation in Thailand, and this tendency will remain during the next 10-15 years. Lignite, like any other coal, structurally consists of aromatic rings connected by bridges of carbon, sulfur, nitrogen, and other heteroatoms. Coals also contain "grains" of mineral matter, basically consisting of aluminosilicates (or clays), sulfides, carbonates, oxides (usually quartz) and chlorides. Besides, heavy metals (HM) are incorporated into the coal structure as either organometallic compounds or inorganic materials, closely associated with the fuel matter. During combustion the mineral compounds are converted to oxides. Fly ash from conventional combustion boilers consists of conventionally seven oxides (SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, Na₂O and K₂O) as well as traces of HM. When fluidized-bed combustion is used, some other compounds (for example, MgCO₃ and CaSO₄) are contained in fly ash leaving the stacks of the power plant.

Almost all chemical elements have been found in various types of coals (including lignites). As for fly ash, the content of various elements in it may vary in the range from the parts per trillion level (ppt) to more than 50 wt. %. The content of heavy metals (HM) for different solid fuels varies from less than 0.5 ppm (for Cd, Hg) up to several thousands ppm (for Ba, Zn) as indicated by Tillman, 1994.

In this work, the highly hazardous HM were the focus of an assessment of environmental impact of the Mae Moh Power Plant fired with Thai lignites.

MATERIALS AND METHODS

Presently, the Mae Moh Power Plant consumes almost all of the lignite used for power generation in Thailand and represents, in effect, the only source of HM emission from the power sector in the country. After the year 2010, Thai lignites will be gradually replaced with imported higher quality coals, which are planned to be fired in new power producing utilities (Chungpaibulpatana et al., 1997).

Thai lignite can be classified as a high sulfur, low-rank coal. Moreover, as time goes by, the fuel quality is being deteriorated. The lignite supplied to the Mae Moh Power Plant from different mines is currently characterized by a low content of carbon (20 - 35 %), a medium moisture content (26 - 35 %), a variable ash content (17 - 41 %), and a high sulfur content (1.7 - 3 %). The nitrogen content varies from 0.8 to 1.25 %, the oxygen content from 7 to 10.7 %, and hydrogen content from 1.8 to 3.2 %. The lignite's lower heating value is estimated to be 10.4 MJ/kg (averaged).

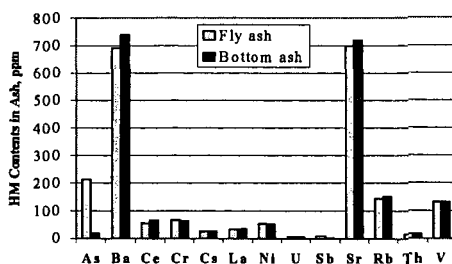


Fig.1. Variability of heavy metals measured in fly and bottom ash of Thai lignite

The most important data used to approach the objectives in our work were found in a paper devoted to determining the X-ray fluorescence analysis of fly and bottom ash (Fig.1) collected from units of the Mae Moh Power Plant (Ratanasthien et al., 1993). As may be seen in Fig.1, data referred to bottom ash confirm that the HM contents are of the same order as ones for fly ash, except for arsenic.

To estimate the emission of ash, we first estimated the total amount of ash (per annum) formed from fuel combustion in steam boilers installed at the power plant. Meanwhile, the SPM emission is associated with ash particles that enter the atmosphere with flue gas, i.e. those that pass through the ash removal equipment arranged downstream from the boilers and remain in the (waste) flue gas. The relevant data (Chungpaibulpatana et al., 1997) for the period of 1990 – 2030 are given in Fig. 2.

At present, the SPM emission is rather high and can be estimated to be about 1/3 of the total ash emission, indicating a low efficiency of ash collecting units used at the power plant. Since new power plants aimed at firing imported coals will be equipped with highly efficient ash collecting devices, the SPM emission is mostly associated with firing lignite, and the data can be used in our work (as given in Fig. 2) for estimating the HM emission from the power plant.

The Mae Moh Fuel-Power Complex (including the power plant) is located in Northern Thailand. The area is bound between 15°N to 20.5°N and 97.5°E to 101.5°E. The climate characteristics of the region (Climatological Division, 1994) and also the vegetation and soil properties of Northern Thailand were used for calculation of pollutants deposition rates and comparison with natural HM content in different soil/ecosystem combinations.

In the case of Thai lignite firing, the synergetic environmental impacts are associated with the presence in the fuel of high quantity of sulfur (1.7 – 3.0 %, in some samples up to 7.0 %) and large number of heavy metals (As, Ba, Ce, Co, Cr, Cs, Ni, U, Rb, Sr, Th, etc). Upon deposition, the synergetic environmental impacts of sulfur and HM are related to the acceleration of biogeochemical migration of most HM under acid conditions. The acidification of tropical soils due to sulfur acidity loading will undoubtedly facilitate the accumulation of many heavy metals in food chains in both terrestrial and aquatic ecosystems (Bashkin & Park, 1998).

The general concept of atmospheric transport and deposition computational method is that the concentration of any substance in air is calculated from its emissions, subsequently transported by (averaged) wind flow and dispersed over the area of interest due to atmospheric turbulence. Basically, the removal of the substances from the atmosphere by wet and dry deposition and photochemical degradation is described in general model algorithms. Meantime, transportation and dispersion of HM in the atmosphere are assumed to be similar to as for other air pollution compounds, for instance, such as SO₂ and the smog compounds (Dutchak et al., 1998).

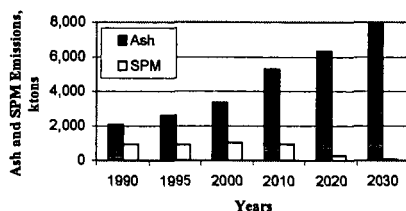


Fig.2. Emissions of ash and SPM (per annum) from the power sector in Thailand

The RAIN-ASIA computational model has been previously applied for the area in the North of Thailand scaled with the $1^{\circ} \times 1^{\circ}$ grid for different time/fuel scenarios based on sulfur deposition predicted data (World Bank, 1994). Some new results have been reconsidered recently using the updated input data (Kozlov&Towprayoon, 1998). Much more detailed studies were carried out by Doolgindachbaporn, 1995, and Ross et al., 1998, for the Mae Moh valley where the power plant is located. The resolutions were from 5 to 10 km cells. Differing in some details, these models indicate the area of most polluted zone as 134 – 179 km², averaged 159 km².

Due to lack of the comprehensive computational model for the HM depositions in the Mae Moh valley, we assume the following two assumptions in selecting the impacted area around the Mae Moh Power Plant:

1. The area of HM dispersion is assumed to be similar to that described in RAIN-ASIA for sulfur deposition, i.e., 20 $1^{\circ} \times 1^{\circ}$ Lola grid cells ranged between 16°N – 20°N and 98°E – 103°E. The total area is as much as 12321 km².
2. The area of HM dispersion is selected to be similar to that described by Doolgindachbaporn (1995) and Ross et al. (1998) for the Mae Moh valley only. The total area is (approximately) 159 km².

These assumptions allow us to estimate the boundary limits for depositions of heavy metals emitted from the Mae Moh Power Plant.

RESULTS AND DISCUSSION

In our study we will consider the toxic metals (according to US EPA classification), namely As, Ba, Cr, Ni and Sb, and also some others, whose emissions are expected to be high. The predicted values on HM emissions are represented in Table 1.

Obviously, HM emissions depend on both emission of SPM from the power plant and HM content in fly ash. The prevailing values of emissions were found for Barium and Strontium, the amounts of those by the year 2000 were estimated to be 716.22 and 726.6 tons/year, respectively.

The emissions of Vanadium, Rubidium, and Arsenic ranged between 120 and 220 tons per year. Relatively small emissions were found for Cesium, Chromium, Nickel, Cerium and Lanthanum (26 – 70 ton/year). The smallest values were found for Uranium, Thorium, and Antimony, they ranged from 5 to 9 tons per year.

However, the environmental impact of the HM depends not only on their emission. Mainly, it is associated with the deposition rates (which depend on the impacted area), relative increase in HM content in soil and some other factors. As mentioned above, two case studies (associated with different impacted areas assumed in computations) have been considered in our work to estimate the dispersion of HM over the area near the power plant.

In the first case study, the total amount of emitted HM was assumed to deposit proportionally to sulfur compounds dispersion over the (maximum) area of 12321 km². The selected year is referred to 1995. According to our assessment, if the impacted area were selected to be 12321 km², in the most polluted $1^{\circ} \times 1^{\circ}$ Lola grid cells, 100°E – 18°N, the deposition rates of HM would

Table 1. Predicted Values of HM Pollution from Power Generation in Thailand, tons

Element	1981	1986	1990	1995	2000	2010
As	29.394	84.561	201.285	196.599	221.094	204.054
Ba	95.22	273.93	652.05	636.87	716.22	661.02
Cr	9.177	26.4005	62.8425	61.3795	69.027	63.707
Ni	7.3554	21.1601	50.3685	49.1959	55.3254	51.0614
Sb	1.1868	3.4142	8.127	7.9378	8.9268	8.2388
Ce	7.4658	21.4777	51.1245	49.9343	56.1558	51.8278
Cs	3.588	10.322	24.57	23.998	26.988	24.908
La	4.5264	13.0216	30.996	30.2744	34.0464	31.4224
U	0.8570	2.46537	5.86845	5.73183	6.44598	5.94918
Rb	19.872	57.168	136.08	132.912	149.472	137.952
Sr	96.6	277.9	661.5	646.1	726.6	670.6
Th	2.3598	6.7887	16.1595	15.7833	17.7498	16.3818
V	18.078	52.007	123.795	120.913	135.978	125.498

have varied from 174 g/km²/year (U) up to 19665 g/km²/year (Sr). The intermediate values are shown for As (5984 g/km²/year), Cr (1868 g/km²/year) and Ni (1497 g/km²/year).

In the second case study the total amount of emitted HM was assumed to disperse evenly over the minimum area of 159 km². If the minimum impacted area were assumed to be 159 km², the values of HM deposition rates would vary from 40,500 g/km²/year (for U) to 4,064,200 g/km²/year (for Sr). The depositions of the most dangerous elements are shown to be equal to 1,236,450 g/km²/year for As, 386,100 g/km²/year for Cr and 309,000 g/km²/year for Ni. No doubt these values are of the great environmental concern for human and ecosystem health.

In spite of the very rough estimation, the predicted values of HM deposition rates are useful for comparison with their natural content in soils of North Thailand. Many considered heavy metals (Ba, Cr, Ni, Cs, La, V) are active biogeochemical migrants and they accumulate in the upper humus soil layer in much more significant amounts in comparison with their local or regional average values in soil and geological rocks, or clarks (Dobrovolsky, 1994). Accordingly, the annual HM deposition rates were compared with both values of HM content in upper humus layer and clarks. The average depth of heavy metal accumulation layer is assumed to be 20 cm.

Calculations have shown that even in the case of maximum area of impacted zone, 12321 km², the annual deposition rates of some heavy metals (As, Ni, Cs, La, V) are equal to 0.2 – 0.5 % of their clarks and achieve 13.5 % for Barium for the area of the most polluted LoLa grid cell of 18°N – 100°E. Nevertheless, many of these metals are biogeochemically active elements and their accumulation is much greater in the upper humus layer. The relative increase in this layer is significantly less and ranges between 0.005 – 0.05 % from corresponding values. Thus, the danger might be connected with As, which could accumulate in soils with annual rate of 0.5 % to the clark value and which is ecologically considered to be one of the most important pollutants.

A much more dangerous scenario can be calculated for the minimum impacted area, 159 km². In this case, even in humus layer the annual increase for biogeochemically active elements achieves 6.43 % for Ba being in range of 0.16 – 3.12 % for other HMs from their content in humus layer. Since the clark values are significantly less than those characterizing an accumulation in humus layer, the relative annual enrichments of HM content in soils are estimated to be between 3.48 % (for Rb) and 103.0 % (for As). These values are undoubtedly dangerous.

The situation is made worse by the synergistic influence of acidification loading from sulfur compounds, which is also dramatic in the region of interest. The increase in acidity of soils and surface waters is known to be accompanied by increasing the mobility of most heavy metals. It leads to possible accumulation of HM in food chains of both terrestrial and aquatic ecosystems.

Table 2 represents the accumulated amounts of HM in soil-biogeochemical fluxes in Tropical Wet Forest ecosystems surrounding the Mae Moh Fuel-Power Complex. The assumption was made that all amount of deposited HM might be accumulated in upper soil layers and could migrate with soil-biogeochemical fluxes of these trace elements. This is reasonable, taking into account high content of Ca and Mg in fly ash of Mae Moh Power Plant. One can see that in case of almost all trace metals (the exception is Sr), the 20 year exploitation of Power plant has led to significant accumulation of HM in the upper soil layers. The values of accumulation might vary from 1.8 ppm for U till 488.0 ppm for Ba. These values have to be added to the natural content of heavy metals in soils. The resulting values are higher than existing environmental quality criteria (limits) for HM contents in soils concerned As, Ba, Cr, Ni, and V (Radojevic and Bashkin,

Table 2. Accumulation of Some HM in Soils over the Minimum Impacted Area (159 km²) (during the period of 1981 – 1999)

Element	Natural content, ppm		Accumulation due to HM emission, ppm
	Upper humus layer	Clark	
As	-	5.0	62.0
Ba	432	0.6	488.0
Cr	197	5.8	19.4
Ni	84	3.2	15.5
Sb	-	1.0	2.51
Cs	20	1.8	7.6
La	80	2.0	9.5
U	-	1	1.8
Rb	-	100	41.9
Sr	-	300	203.5
V	212	3.2	38.1

1999). Furthermore, in many cases the content of HM is higher than the requirements for the remediation, even for commercial or industrial land use.

CONCLUSIONS

1. The emissions and environmental effects of heavy metals from the lignite-burned Mae Moh Power Plant (Northern Thailand) were estimated for the 30-years period from early 80's to year 2010. With increase in power production late in 90's and early in the next century, the major values of emissions were found for Barium and Strontium (more than 650 tons per year). The emissions of Vanadium, Rubidium, and Arsenic ranged between 120 and 220 tons per year. Relatively small emissions were calculated for Cesium, Chromium, Nickel, Cerium and Lanthanum (26 - 70 ton/year). The minimum values were shown for Uranium, Thorium and Antimony, ranging from 5 to 9 tons/year.
2. If the impacted area were considered as minimum one (159 km²), the values of HM deposition rates might be varied in the range from 0.04 (for U) to 4.1 (for Sr) ton/km²/year. The deposition rates, ton/km²/year, of the most dangerous elements were roughly estimated be 1.2 for As, 0.4 for Cr and 0.3 for Ni. If the impacted area were treated as 12321 km², the deposition rates of heavy metals for the most polluted 1°x1° Lola grid cells (100°E - 18°N) in 1995 would have varied from 0.174 (for U) up to 19.7 kg/km²/year (for Sr). The intermediate values were found for As (6.0 kg/km²/year), Cr (1.9 kg/km²/year) and Ni (1.5 kg/km²/year).
3. The 20-years period of exploitation of the Mae Moh Power Plant has led to significant accumulation of HM in the upper soil layer and their migration with soil-biogeochemical fluxes in the Tropical Wet Forest ecosystems surrounding the plant. The values of HM accumulation were estimated to vary from 1.8 ppm (for U) to 488.0 ppm (for Ba). Being added to the natural content of heavy metals in soils, the resulting values for As, Ba, Cr, Ni, and V are higher than the environmental quality criteria (limits) for HM contents in soils. In many cases, the contents of HM exceed the respective requirements for the remediation, even for commercial or industrial land use.

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